IN-39
62349
P-25

NASA Technical Memorandum 104506

Space Station Freedom Solar Dynamic Modules Structural Modelling and Analysis

Charles Lawrence
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

and

Ron Morris
Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio

(NASA-TM-104506) SPACE STATION FREEDOM SOLAR DYNAMIC MODULES STRUCTURAL MODELLING AND ANALYSIS (NASA) 25 p CSCL 20K

N92-15405

Unclas

G3/39 0062349

December 1991

NASA

SPACE STATION FREEDOM SOLAR DYNAMIC MODULES STRUCTURAL MODELLING AND ANALYSIS

Charles Lawrence
National Aeronautics and Space Adminsitration
Lewis Research Center
Cleveland, Ohio 44135

Ron Morris
Sverdrup Technology, Inc.
Lewis Research Center
Brook Park, Ohio 44142

E-6367

Introduction

In support of the Space Station Freedom Solar Dynamic Power Module effort, structural design studies were performed to investigate issues related to the design of the power module, its pointing capabilities, and the integration of the module into the Space Station Freedom infrastructure (fig. 1). Of particular concern from a structural viewpoint are the dynamics of the power module, the impact of the power module on the Space Station dynamics and controls, and the required control effort for obtaining the specified Solar Dynamic Power Module pointing accuracy.

Structural analyses were performed to determine the structural dynamics attributes of both the existing and the proposed SD module designs. The objectives of these analyses were to:

1. Generate validated Solar Dynamic Power Module NASTRAN finite element models.
2. Combine Space Station and power module models into integrated system models.
3. Perform finite element modal analyses to assess the effect of the relocations of the power module C.M. (Center of Mass), and provide modal data to controls designers for controls system design.

Modeling Overview

The Lewis concept finite element model for the Solar Dynamic Module utilizes the same radiator, receiver, and concentrator as the Rocketdyne model. The major differences between the models are depicted by comparing figures 2 and 3. The most significant differences are in the devices used for pointing the module. While the Rocketdyne design has three pointing degrees of freedom, the Lewis design only requires two. In the Rocketdyne design, a "ringed" gimbal system with two degrees of freedom is used for elevation and fine azimuth pointing. Coarse azimuth pointing is performed in the Beta gimbal located at the base of the module in the station main truss. Elevation and fine pointing actuation is performed by linear actuators attached to the rings. The centers of rotation of the ringed system are located considerably apart from the center of mass of the module, therefore creating a constant mass imbalance.

In the Lewis concept pointing is accomplished using one of two alternative designs. For both designs the entire solar dynamic module, including the radiator, is suspended off of the elevation degree of freedom which in turn is supported by a support truss. The elevation degree of freedom is closely located near the modules center of mass to minimize mass imbalance. All of the azimuth pointing is accomplished in the beta joint.

Once the SD module F.E. model was complete, the finite element model for the coupled Solar Dynamic/Space Station Freedom system was created by attaching the SD module to an early version model of the Space Station. Then, using the finite element program MSC/NASTRAN, Solution Sequence 63 for Normal Modes Analysis, natural frequencies and mode shapes were computed. This modal information then was transferred to the EASY5 software package for subsequent controls studies.

Actuated Degrees of Freedom

To accommodate the control system, the structural dynamic finite element model was modified to include the controlled degrees of freedom (fig. 4 and table I). In total, the station configuration used for this study will have fourteen controlled internal degrees of freedom; two for each SD module, two alpha joints, and eight Beta joints for Photovoltaic (PV) arrays. In addition, there also will be six station keeping degrees of freedom.

To simplify the present study, only four internal and six station keeping degrees of freedom will be used. The Solar Dynamic (SD) module on the starboard side of the station, which is modelled with a high level of fidelity, will include both of it's controlled degrees of freedom, while the SD module at port side, which is modelled as a lumped mass at the end of a rigid bar, will be fully constrained. The Beta joints for the PV arrays also will be locked.

Two models, referred to as 'A' model and 'B' model were generated. For the 'A' model the Beta joint is used for azimuth control and elevation control is performed by a Fine Pointing System (FPS) gimbal near the SD center of mass (C.M.). For the 'B' model the FPS is locked and elevation control is performed by adding an additional degree of freedom, just above the Beta joint. The tradeoffs between the 'A' and 'B' models are discussed subsequently.

Inertia Properties

The mass breakdown, center of mass locations, and inertia properties for the Lewis SD, 'A' model design, are given in tables II-IV and figures 5 and 6. The mass is grouped into a subtotal and a total. The subtotal includes all components which are actuated at the fine pointing (elevation degree of freedom). The total includes all components actuated at the Beta gimbal which includes the subtotal components plus the components between the fine pointing system and the Beta gimbal. The mass for the major module elements (radiator, receiver, and concentrator) is taken from Rocketdyne's SD Power Module Mass Summary (6/5/90) since these elements are unchanged from the Rocketdyne design. The mass for the rest of the components is estimated based on the Lewis modified design concept.

The center of mass (C.M.) locations of the SD Power Module (fig. 5) were determined from the finite element model by integrating the mass distribution of the individual component elements. A C.M. was computed for both the sub-components actuated by the fine pointing system and those actuated by the Beta gimbal. As shown in Detail 'A', both the 'A' and 'B' models have their C.M. near the center of the fine pointing system. It was desired that the C.M. be near the fine pointing system to minimize the required control efforts.

The inertia properties (tables III and IV) also are computed separately for the sub-systems actuated by the fine pointing system and Beta gimbal. The coordinate system corresponding to these properties is shown in figure 5. These properties are used for the rigid body controls studies as well as the computation of gravity gradient loadings. The inertias for the entire SD/Station model are shown in figure 6.

Modal Results

Two sets of modal data were generated. The sets pertain to the 'A' and 'B' models of the coupled SD/Station system. Although these models are basically identical, the locations of their controlled degrees of freedom are different. As a result, their respective modal properties differ. A comparison of their natural frequencies is shown in table V. The first fifteen modes for the 'A' model are in figures 7 to 26. Both sets of modal data are used for subsequent controls-structures interaction studies.

Modal analyses using three eigenvalue extraction methods, enhanced inverse power iteration, modified Givens, and Lanczos, were performed. All three produced similar results. However, because Lanczos is recommended by MSC for large models and because these analyses showed it to be several times more efficient in terms of computer CPU time, Lanczos is recommended for any future analyses of this kind.

Initial modal analyses showed rigid body eigenvalues in the 1×10^{-4} range, which is higher than one would expect for good results. After consultation with MSC, it was found that using a small negative number instead of zero (this analysis used -0.1) for the starting point of the frequency range of interest corrected this problem and produced more stable results in general. This practice is recommended for any future analyses where rigid body modes are of interest.

Problems were also encountered in releasing degrees of freedom (DOF) to represent the Beta gimbal and fine pointing system. It was found that, if the rotation and elevation degrees of freedom were too close together geometrically, an incorrect number of rigid body modes would be calculated. For this model, a separation of thirty inches produced good results. At the time this model was created, the actual dimensions were unknown. Both CBAR elements with pin flag specifications and RBAR rigid elements with the proper DOF being independent were used to model the rotation and elevation DOFs with no significant differences.

Analyses were run both with and without temporary grounding of the six full structure rigid body modes through MSC/NASTRAN SUPORT cards. These runs showed no significant differences, which generally indicates numerical conditioning of the model is good.

Final Remarks

During 1990 Solar Dynamic Power was being considered as a post- assembly add on to Space Station Freedom. In support of this effort the Solar Dynamic Power System Branch at NASA Lewis examined various aspects of the power module and it's implementation into Space Station Freedom, including a possible redesign of the power module proposed by Rocketdyne. Dynamics and Controls was a major element of the redesign investigation. In 1991, as a result of budget constraints, the Space Station Freedom Program was rescoped and Solar Dynamic Power was eliminated from the program. For archival purposes, this report attempts to summarize the structural dynamics work performed in conjunction with the redesign studies.

TABLE I.—FINITE ELEMENT MODEL CONTROL POINT DESCRIPTIONS

Grid	Description	X-CRD. (IN)	Y-CRD. (IN)	Z-CRD (IN)
17 410	Beta (θ_Z) rotation	0	3 937	125
17 310		0	3 937	95
16 094	End of truss	0	3 937	0
16 070		0	-3 937	0
16 098	Solar dynamic lumped mass	33	-3 938	325
16 301	Docking station	-197	-127	-742
16 303	RCS JETS	-184	-1 234	0
16 304	RCS JETS	184	-1 234	0
16 305	RCS JETS	-184	1 234	0
16 306	RCS JETS	184	1 234	0
16 307	RCS JETS	-184	-1 224	10
16 308	RCS JETS	184	-1 224	10
16 309	RCS JETS	-184	1 224	10
16 310	RCS JETS	184	1 224	10
7 181	Radiator tip	98	3 935	951
7 193		410	3 935	951
11 028	Sun sensors	-129	3 784	900
11 106		-129	4 090	900
'A' model				
17 006	Out-board elevation (θ_Y)	0	3 930	479
17 007	At fine pointing, 'A' model	0	3 943	479
17 167	In-board elevation (θ_Y)	0	3 950	479
17 168	At fine pointing, 'A' model	0	3 924	479
'B' mode				
17 010	Elevation (θ_Y), 'B' model	0	3 937	155
17 410		0	3 937	125

TABLE II.—MASS BREAKDOWN
LEWIS DESIGN SOLAR DYNAMIC MODULE

Component	Weight, lb	X C.G.[a]	Y C.G.*[a]	Z C.G.[a]
Radiator	3 060	—	—	—
Concentrator	1 946	—	—	—
Receiver	5 601	—	—	—
Struts	88	—	—	—
Cradle	629	—	—	—
Gimbal	289	—	—	—
Subtotal	11 613	462[c]	0[c]	-29[c]
Fine pointing System location	—	479	0	0
Gimbal truss	415	—	—	—
Base plate	350	—	—	—
Beta gimbal[b]	420	—	—	—
Total	12 798	440[c]	0[c]	-27[c]

[a]See figure for coordinate system and reference point.
[b]Assumes all gimbal weight actuated by gimbal.
[c]Preliminary values–to be updated.

TABLE III.—FINE POINTING SYSTEM INERTIAS

Mass

$$M = \begin{bmatrix} 11\,613 & 0 & 0 \\ 0 & 11\,613 & 0 \\ 0 & 0 & 11\,613 \end{bmatrix} \frac{1}{g}$$

Rotational inertia

$$I = \begin{bmatrix} 5.8\times10^{8} & 2.5\times10^{6} & 1.8\times10^{7} \\ 2.5\times10^{6} & 8.6\times10^{8} & 4.6\times10^{5} \\ 1.8\times10^{7} & 4.6\times10^{5} & 4.1\times10^{8} \end{bmatrix} \frac{1}{g}$$

TABLE IV.—BETA SYMBOL INERTIAS

Mass

$$M = \begin{bmatrix} 12\,798 & 0 & 0 \\ 0 & 12\,798 & 0 \\ 0 & 0 & 12\,798 \end{bmatrix} \frac{1}{g}$$

Rotational inertia

$$I = \begin{bmatrix} 1.8\times10^{9} & 2.5\times10^{6} & -9.3\times10^{7} \\ 2.5\times10^{6} & 2.1\times10^{9} & 3.8\times10^{6} \\ -9.3\times10^{7} & 3.8\times10^{6} & 4.1\times10^{8} \end{bmatrix} \frac{1}{g}$$

TABLE V.—COMPARISON OF NATURAL FREQUENCIES

Move number	'A' model, Hz	'B' model, Hz
1-10	0.0 (rigid body)	0.0 (rigid body)
11	.056	.057
12	.062	.062
13	.122	.122
14	.145	.135
15	.156	.145
16	.249	.215

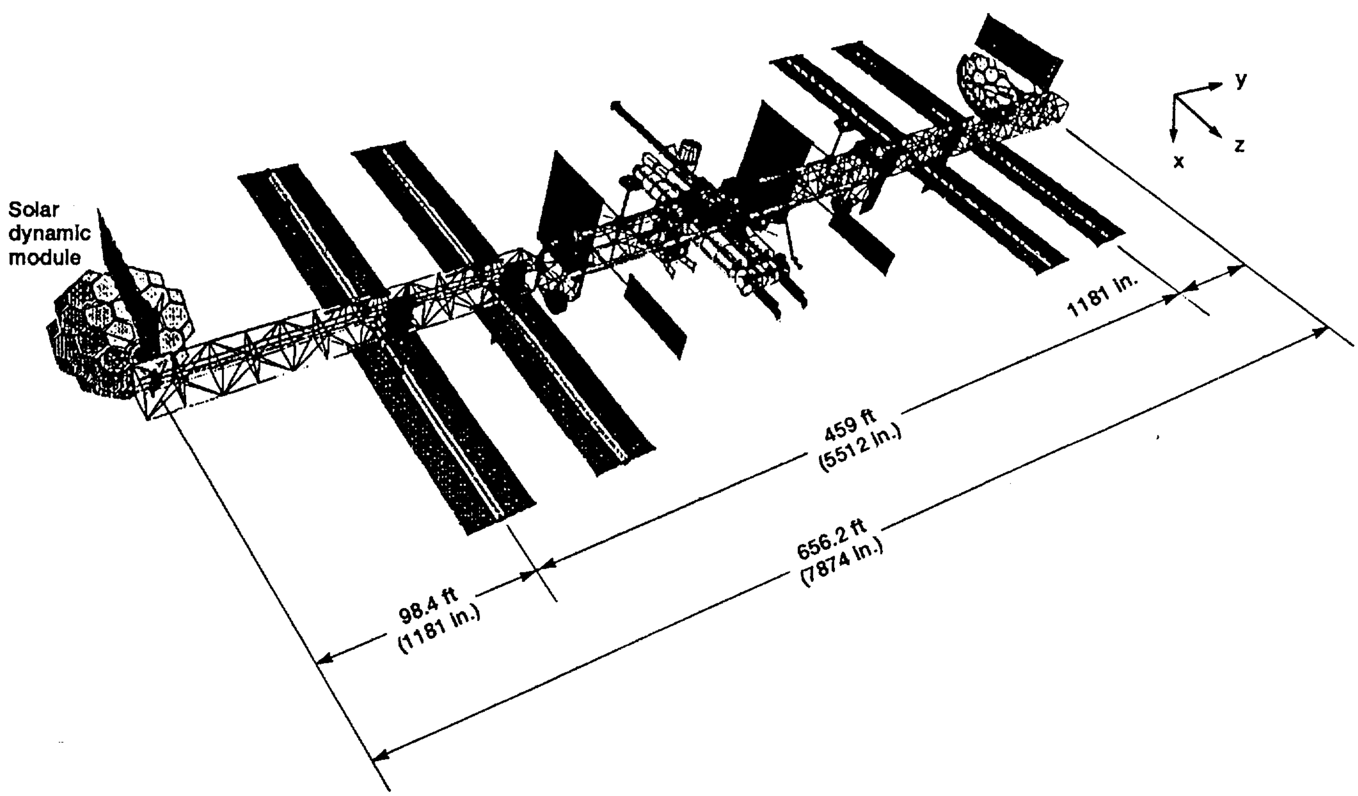


Figure 1.—Space Station Freedom with solar dynamic modules.

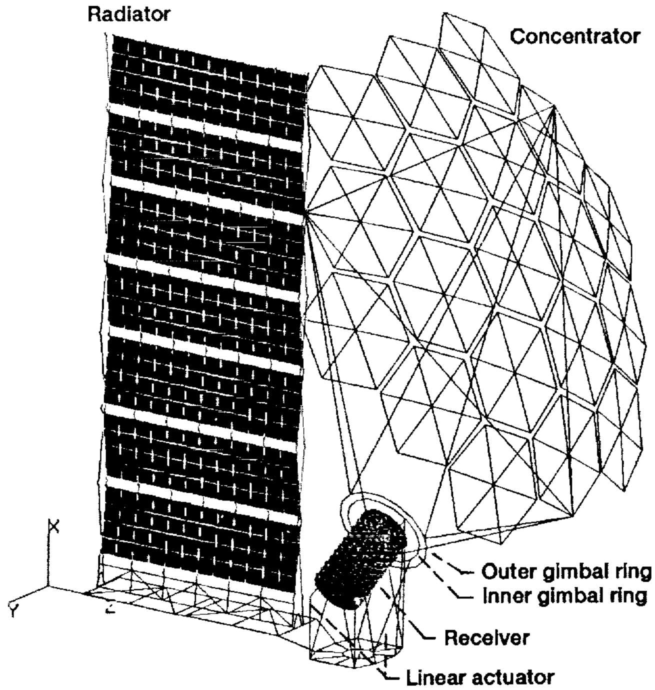


Figure 2.—Rocketdyne solar dynamic module F.E. model.

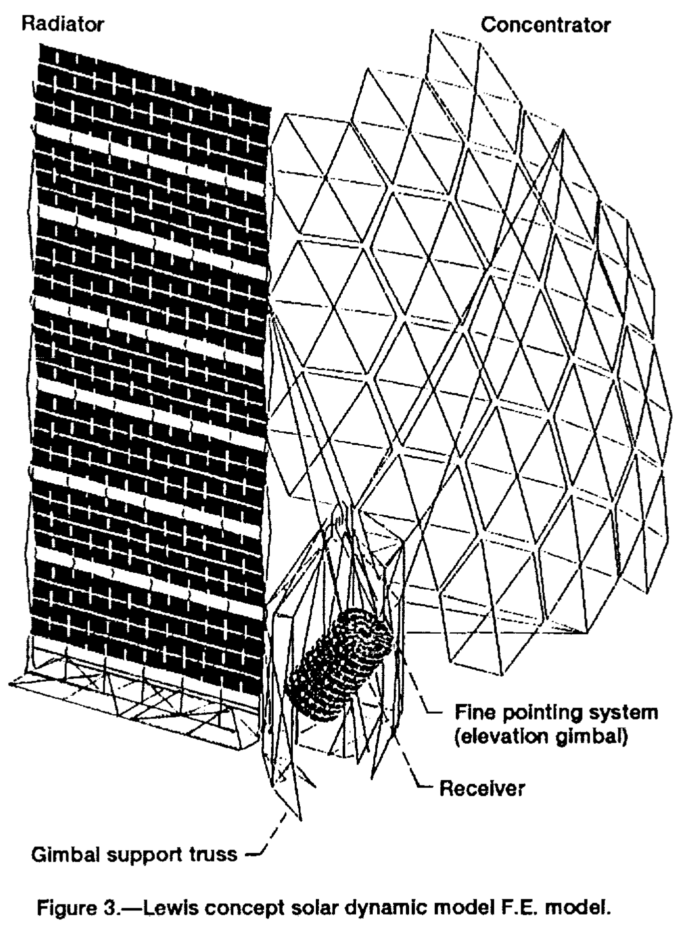


Figure 3.—Lewis concept solar dynamic model F.E. model.

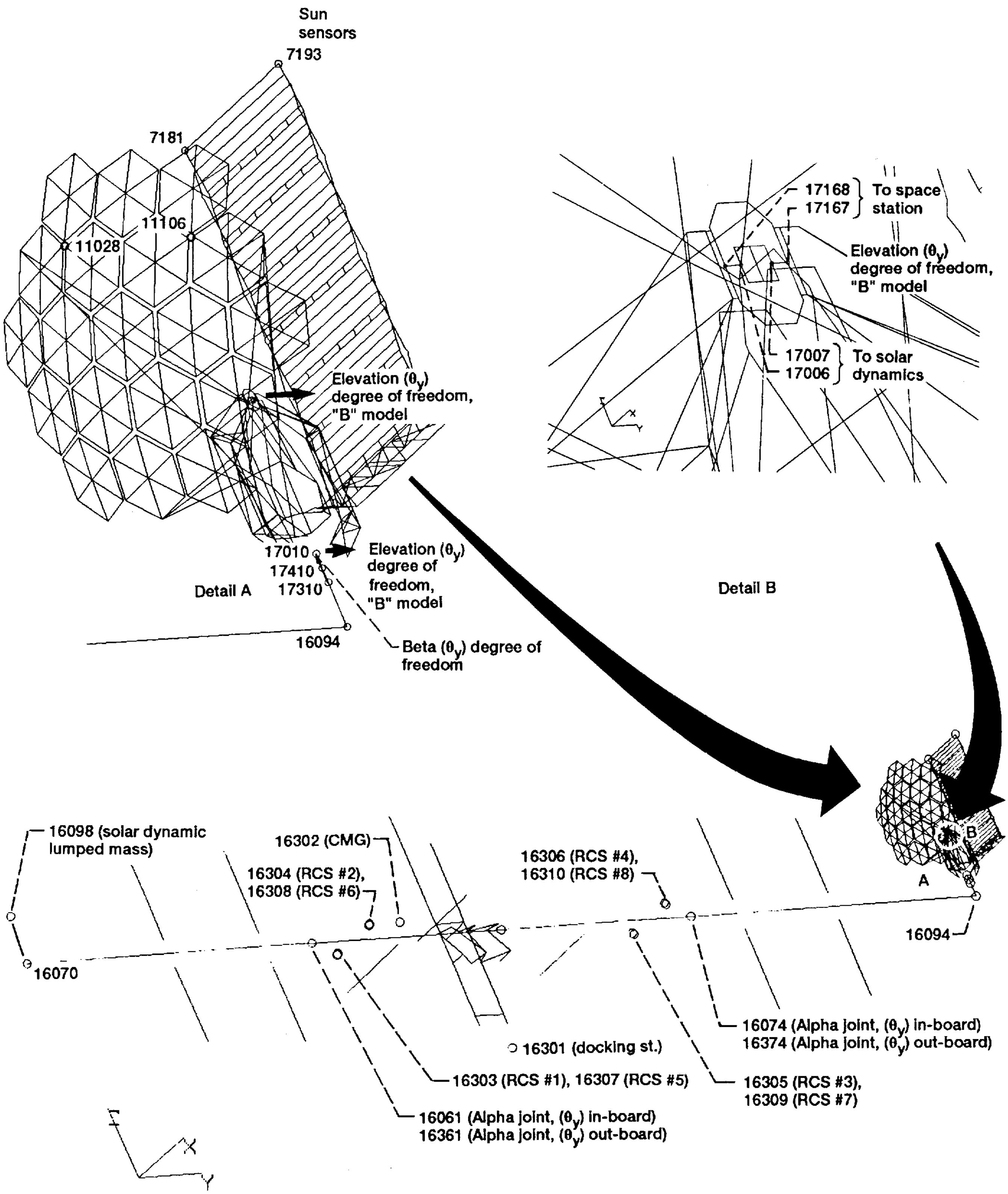
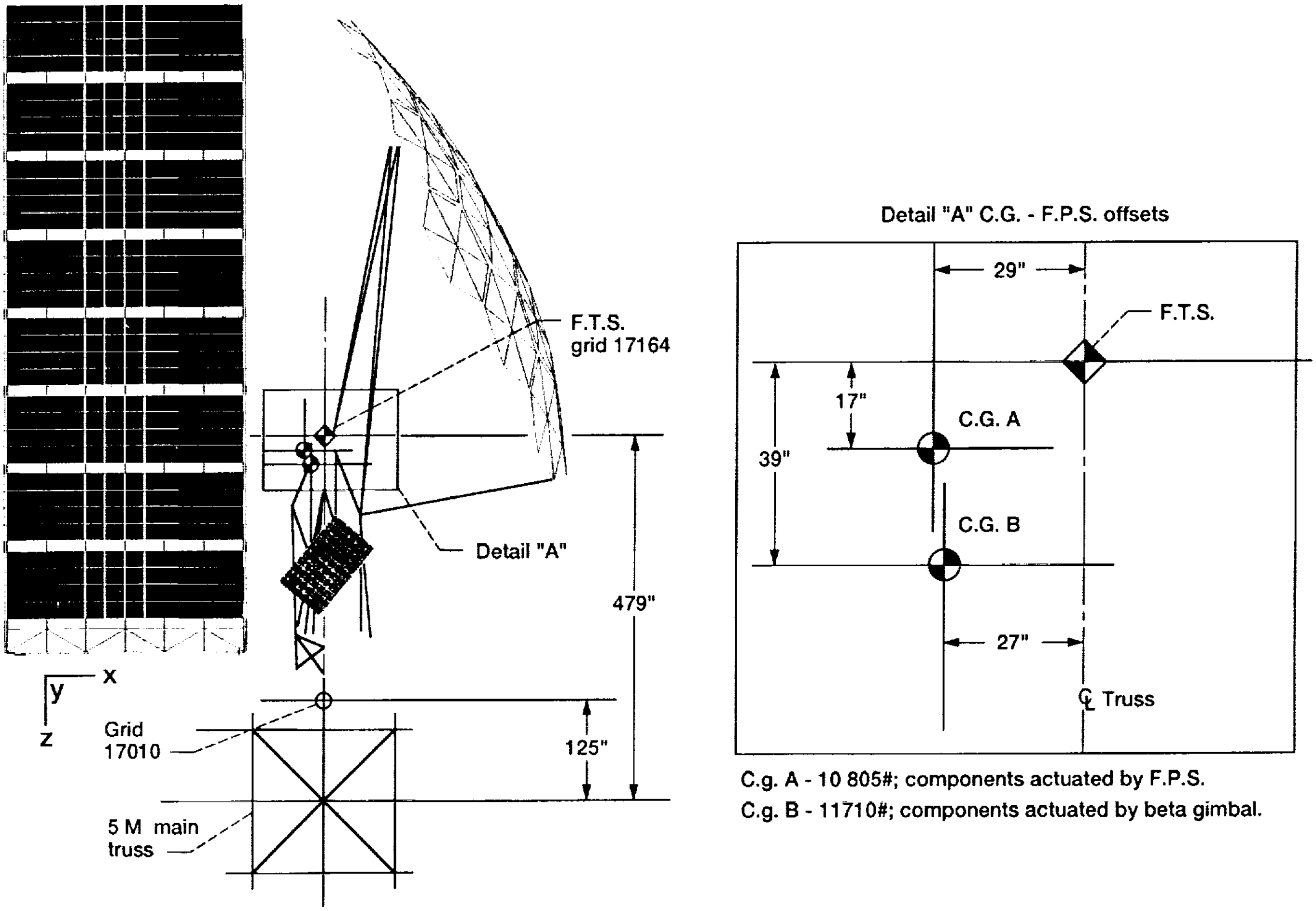
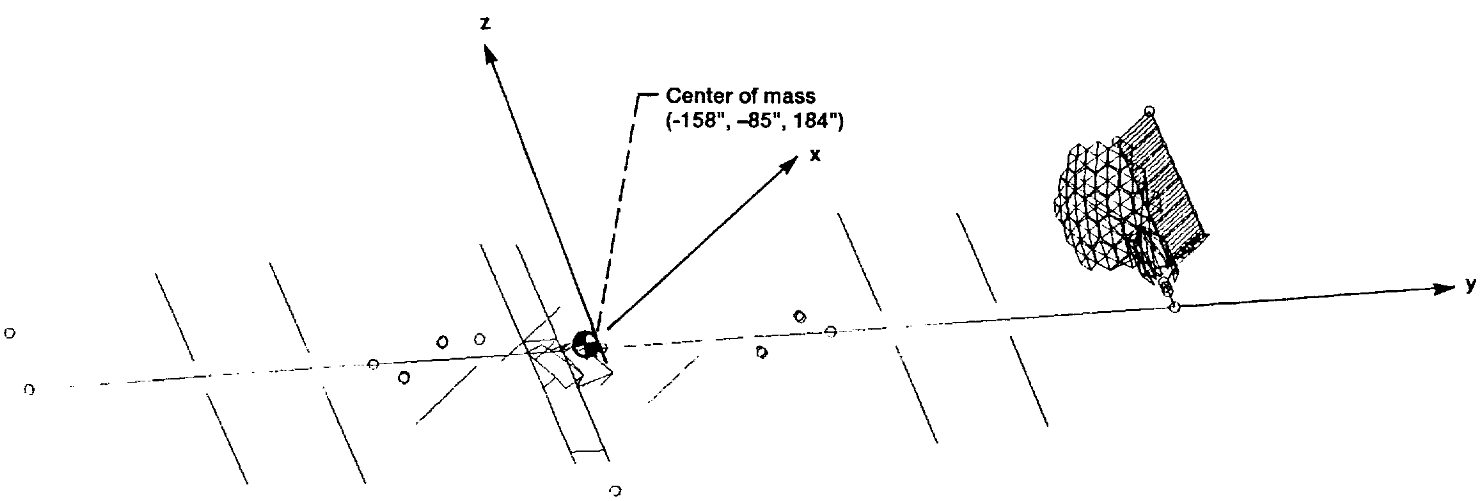


Figure 4.—Solar dynamic/Space Station finite element model (control system model).



C.g. A - 10 805#; components actuated by F.P.S.
C.g. B - 11710#; components actuated by beta gimbal.

Figure 5.—Solar dynamic module centers of mass.



$$\text{Total mass} = 4.24\times10^{5}\ \frac{\text{lb}}{\text{g}} \qquad I = \begin{bmatrix} 8.3\times10^{11} & -1.3\times10^{10} & 1.8\times10^{10} \\ -1.3\times10^{10} & 8.5\times10^{10} & 7.3\times10^{9} \\ 1.8\times10^{10} & 7.3\times10^{10} & 7.9\times10^{11} \end{bmatrix} \frac{\text{in}-\text{lb}}{\text{g}}$$

Figure 6.—Solar dynamic/station inertia properties.

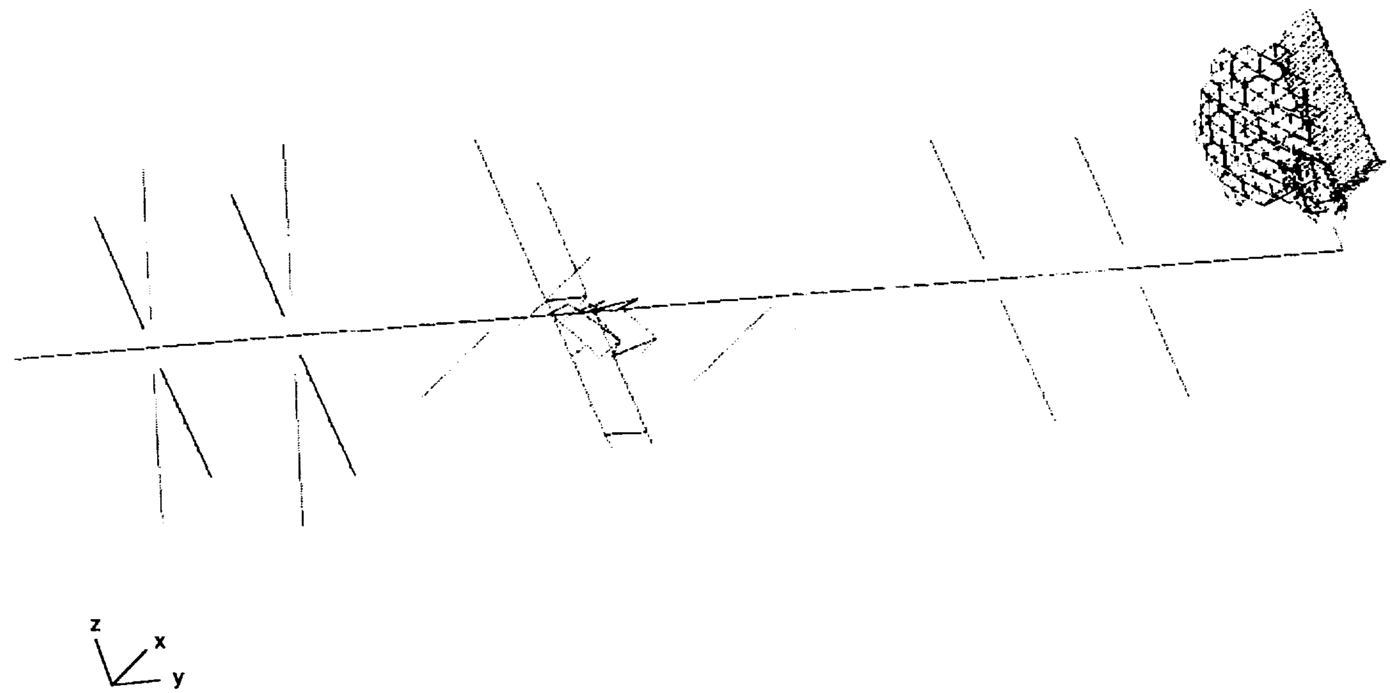


Figure 7.—"A" model, mode 1 (rigid body).

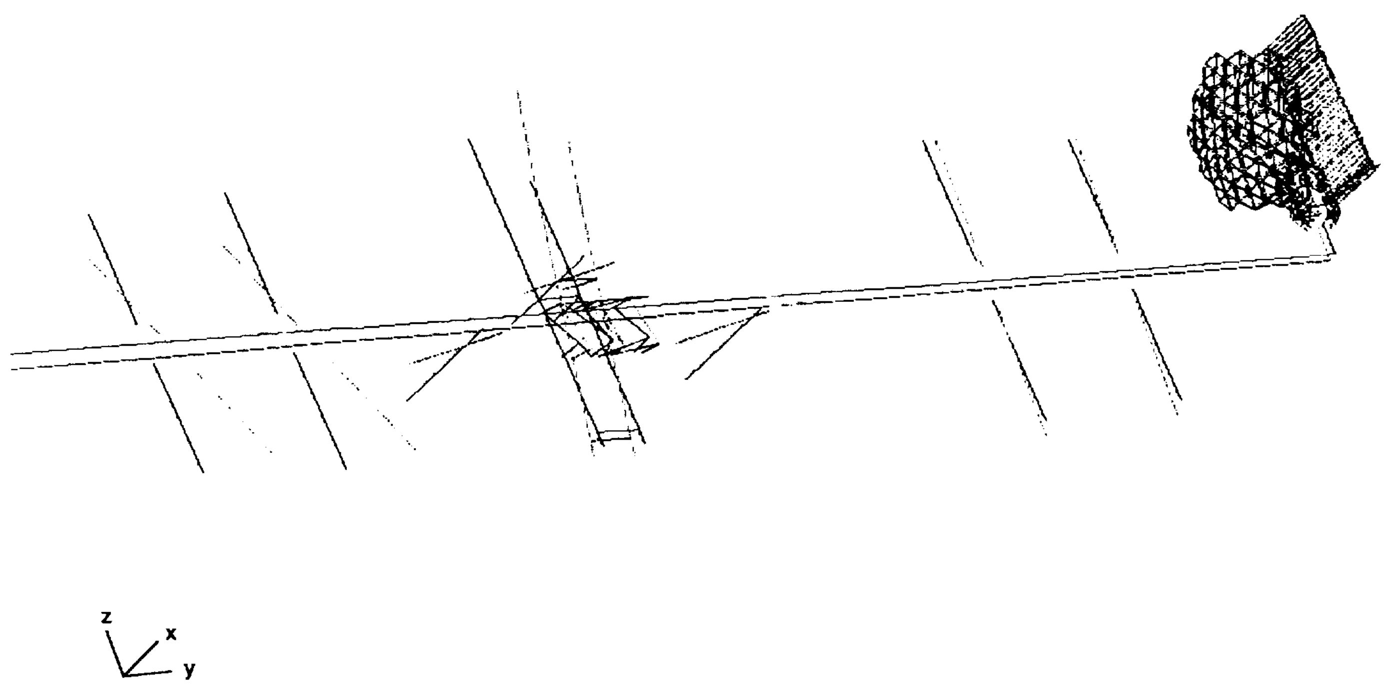


Figure 8.—"A" model, mode 2 (rigid body).

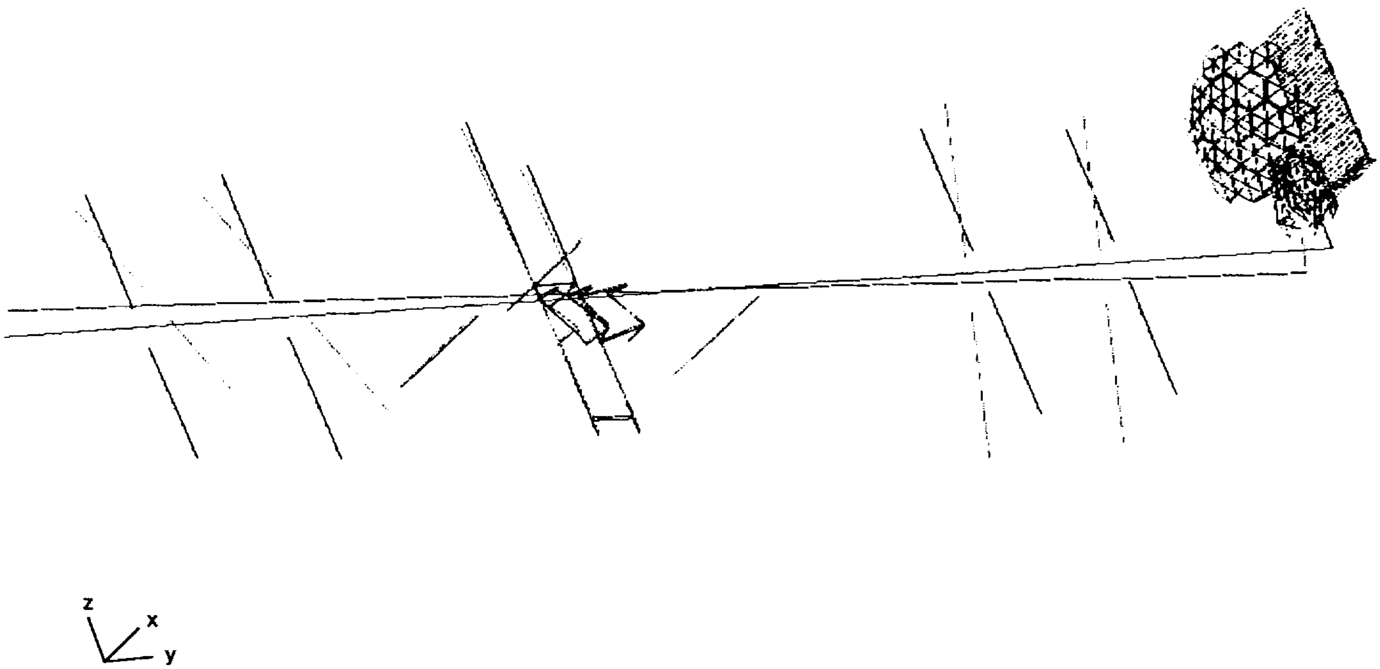


Figure 9.—"A" model, mode 3 (rigid body).

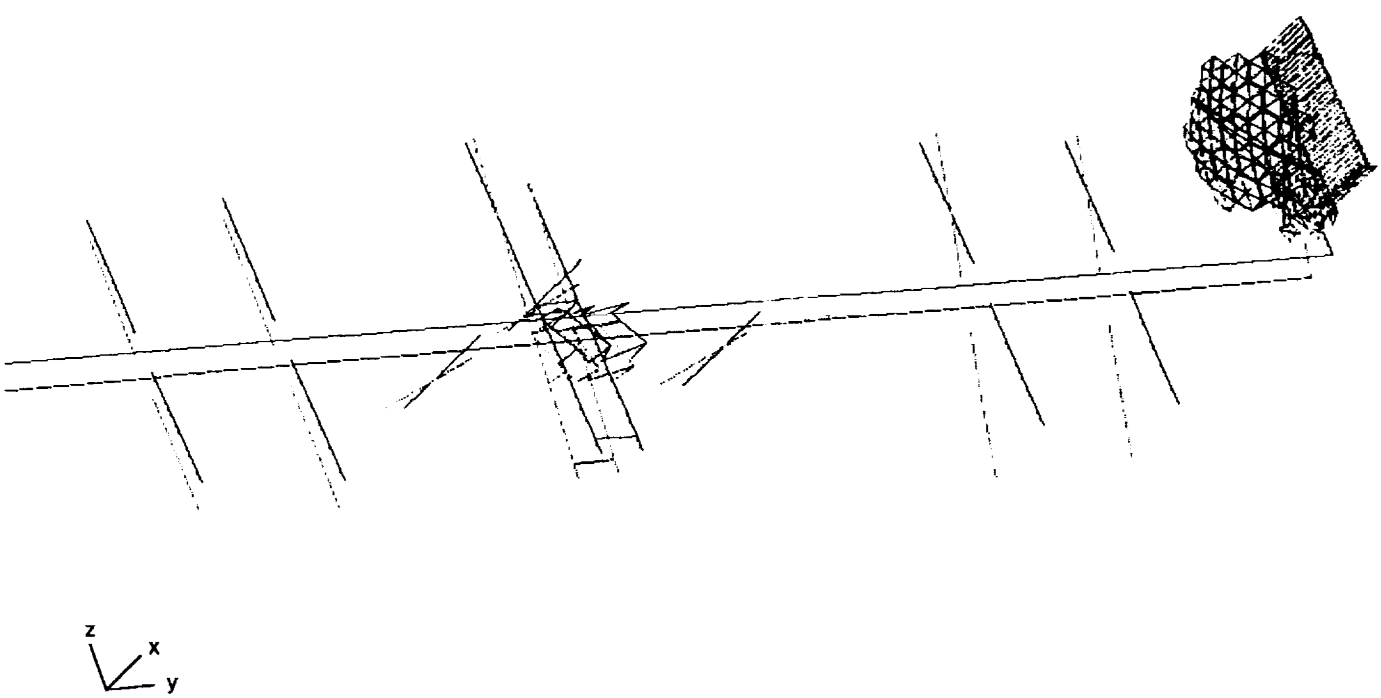


Figure 10.—"A" model, mode 4 (rigid body).

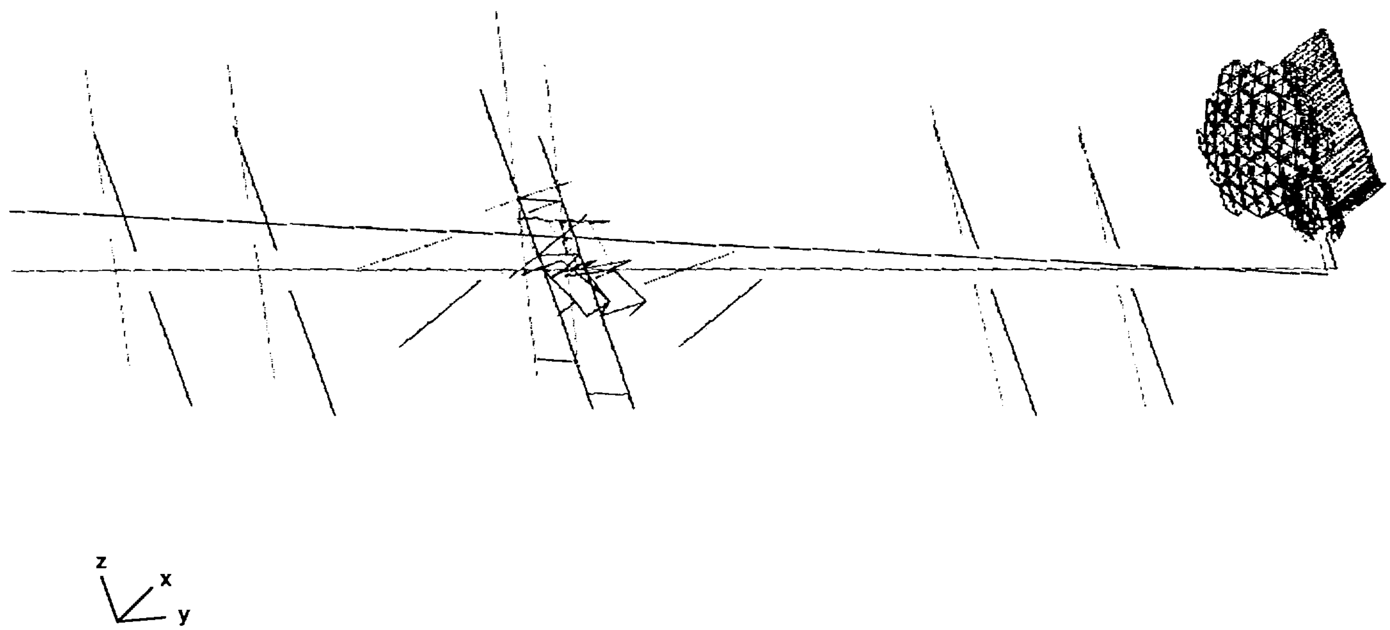


Figure 11.—"A" model, mode 5 (rigid body).

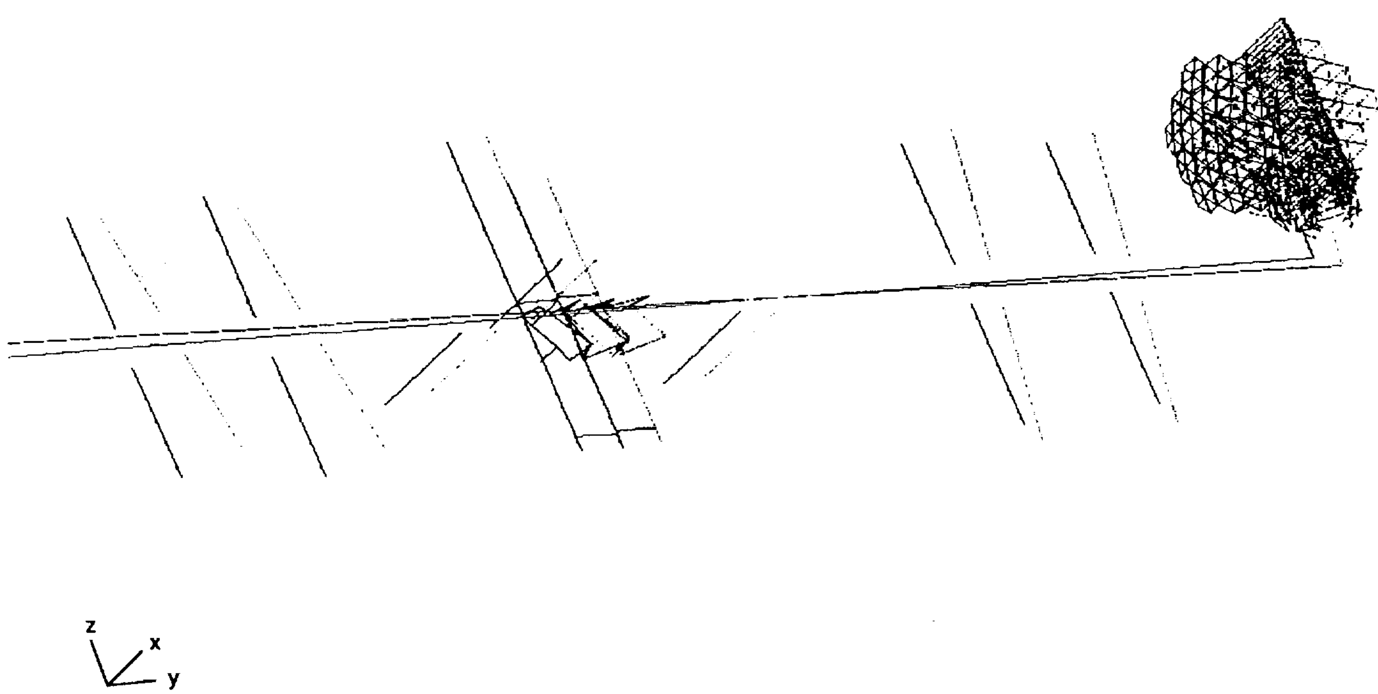


Figure 12.—"A" model, mode 6 (rigid body).

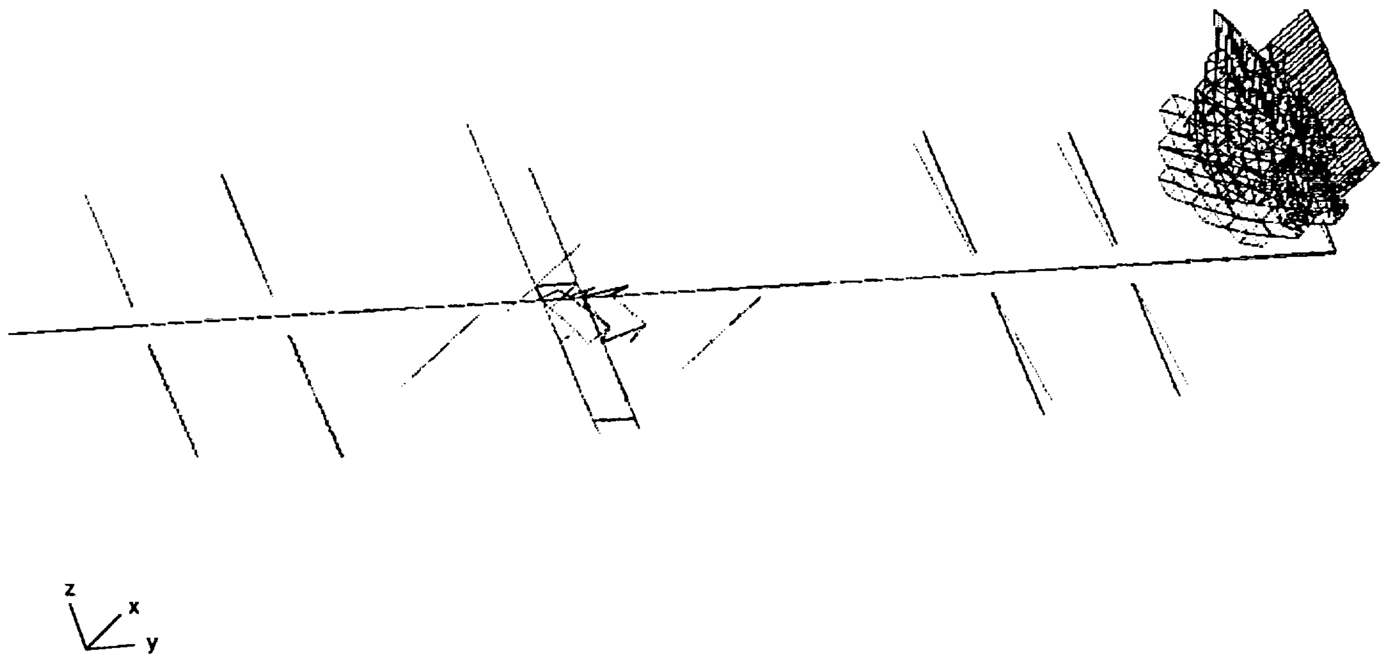


Figure 13.—"A" model, mode 7 (rigid body).

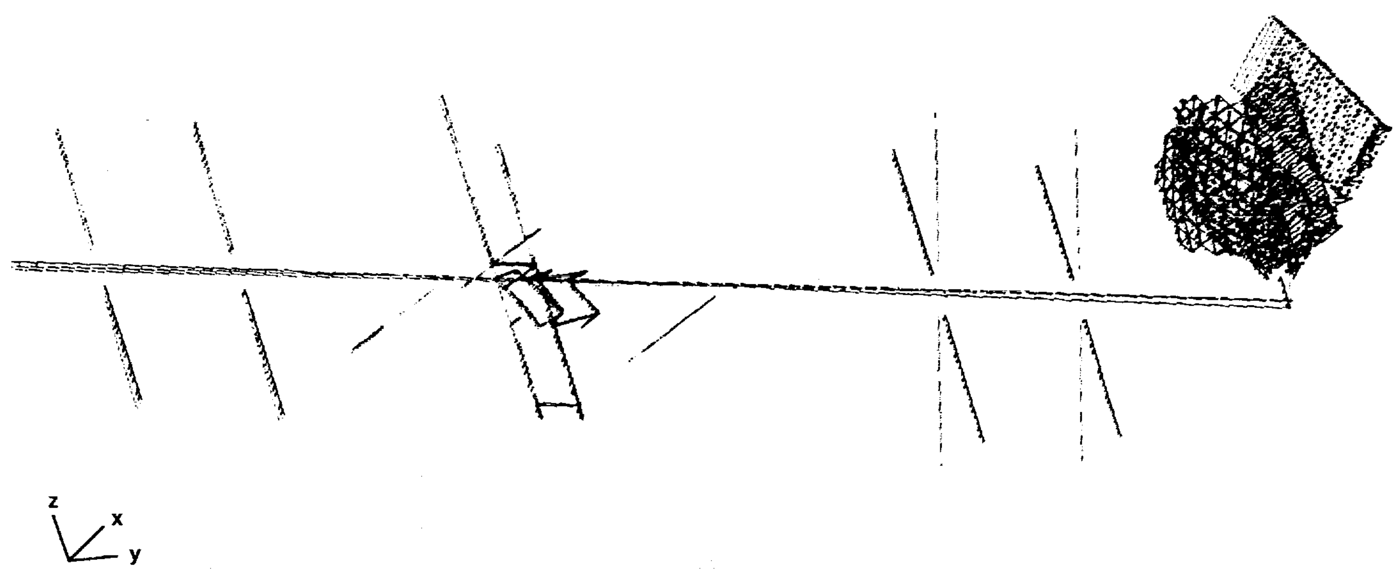


Figure 14.—"A" model, mode 8 (rigid body).

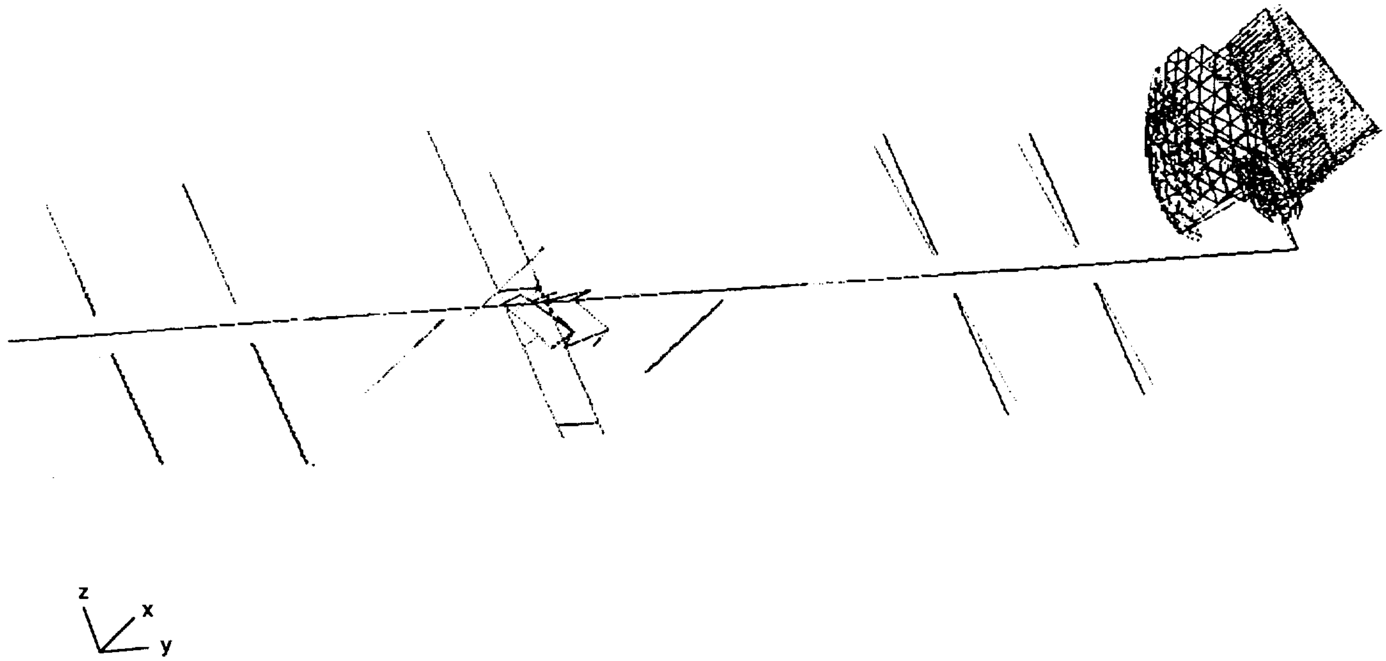


Figure 15.—"A" model, mode 9 (rigid body).

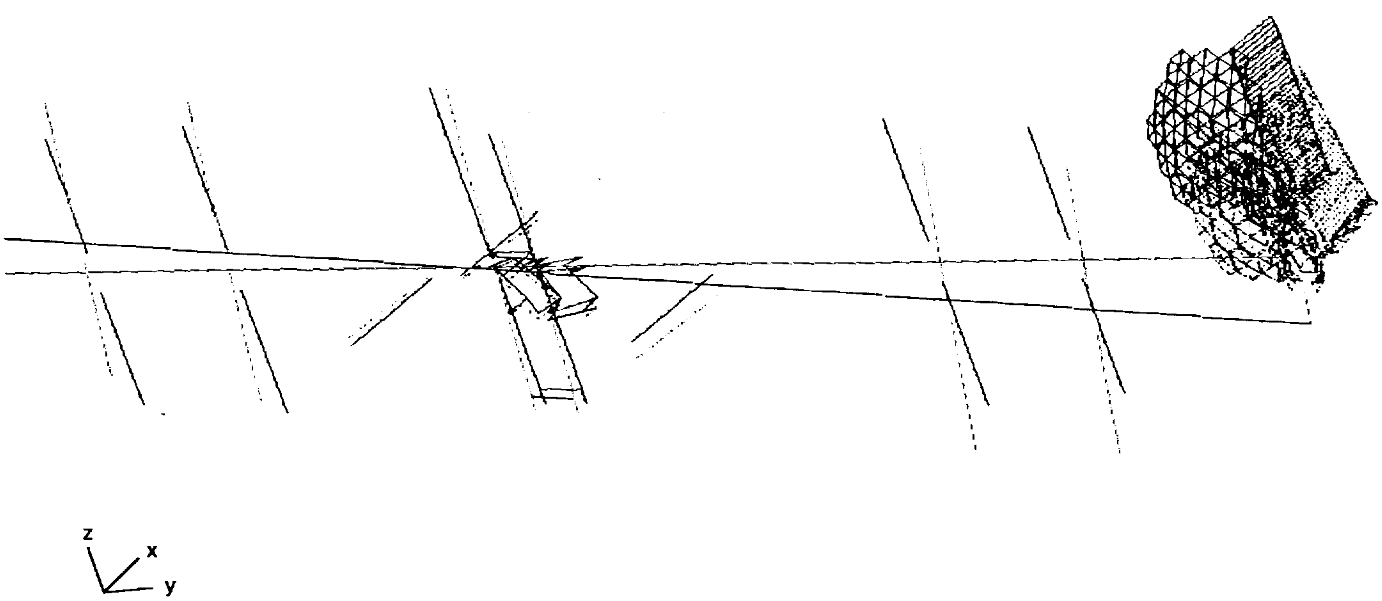


Figure 16.—"A" model, mode 10 (rigid body).

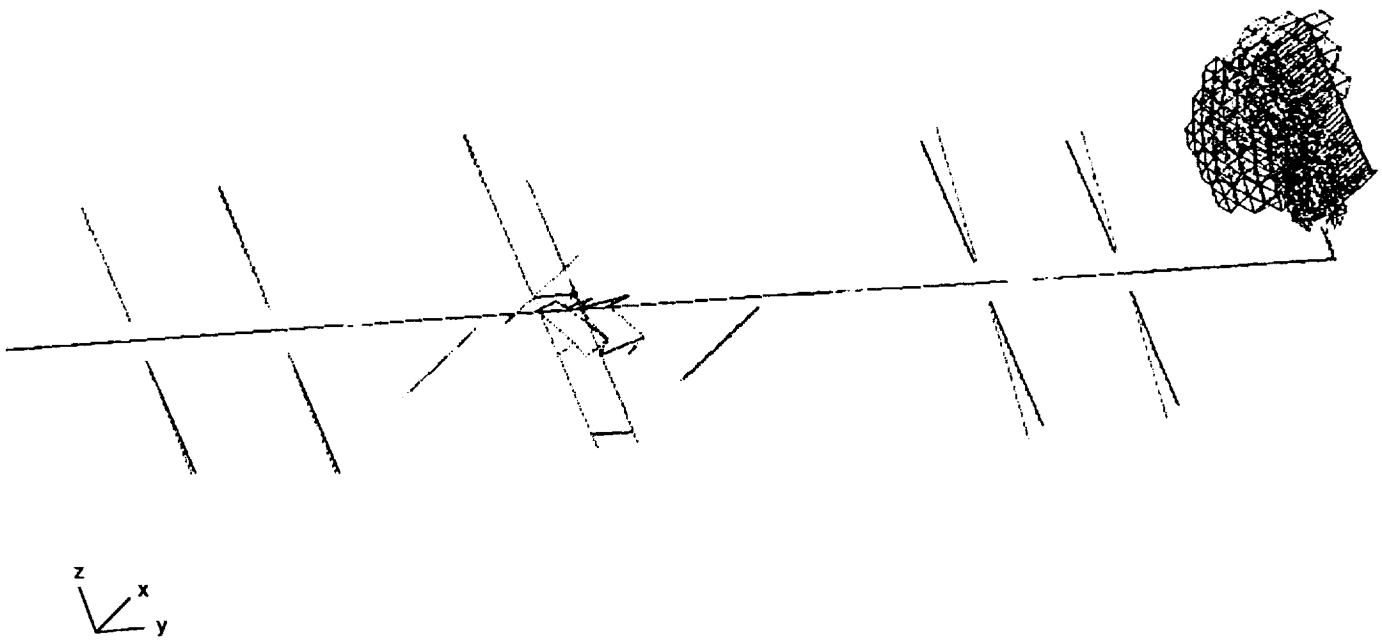


Figure 17.—"A" model, mode 11 (elastic).

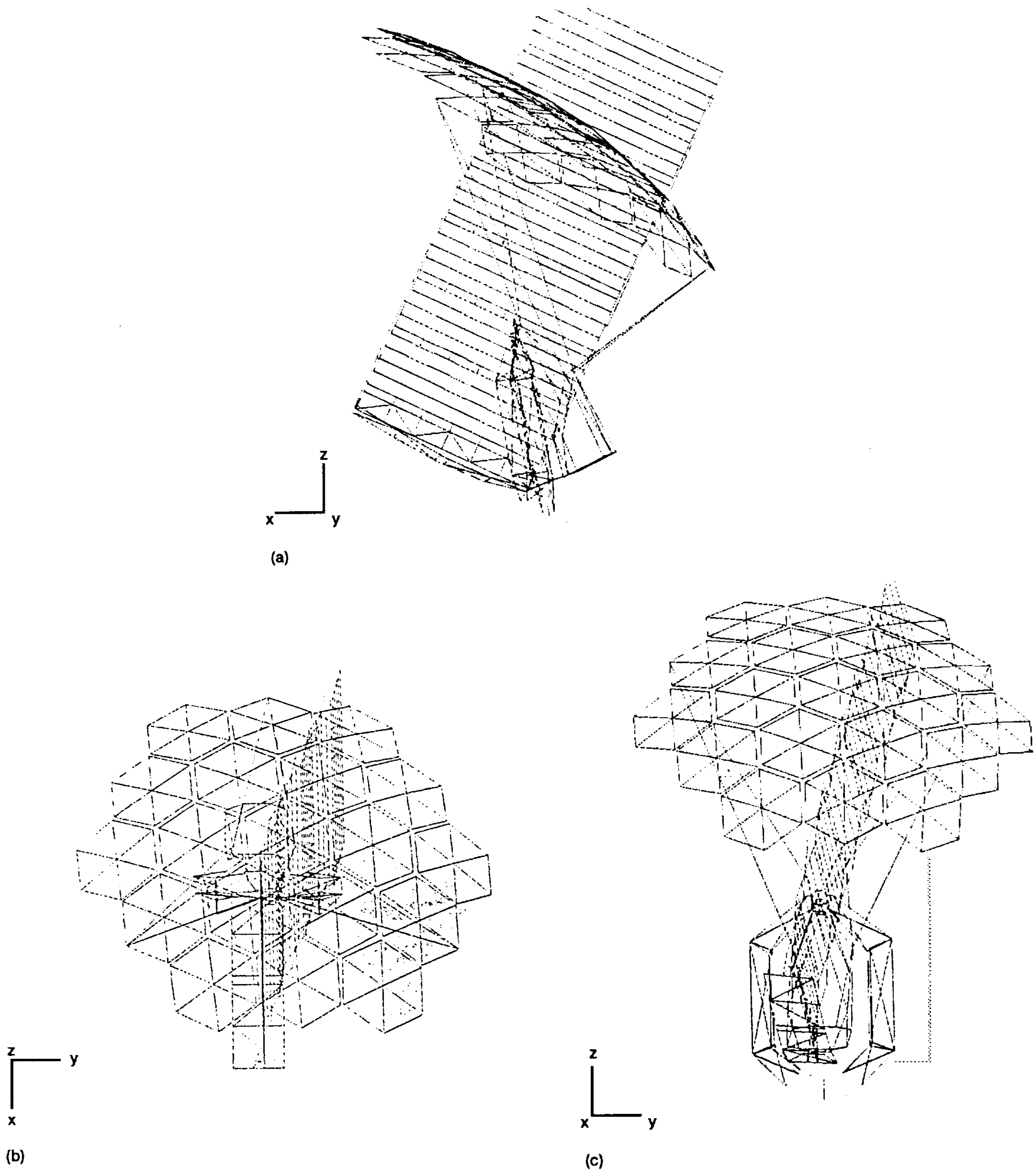


Figure 18.—"A" model, mode 11 (elastic).

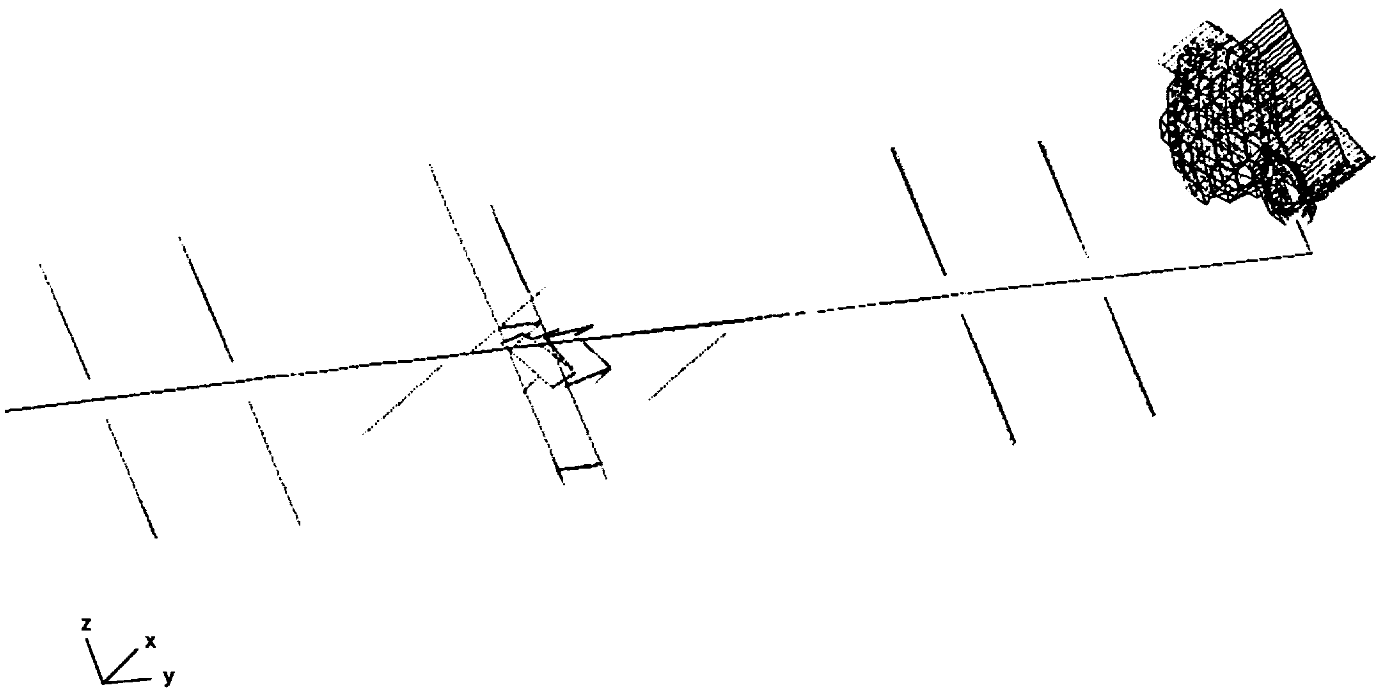


Figure 19.—"A" model, mode 12.

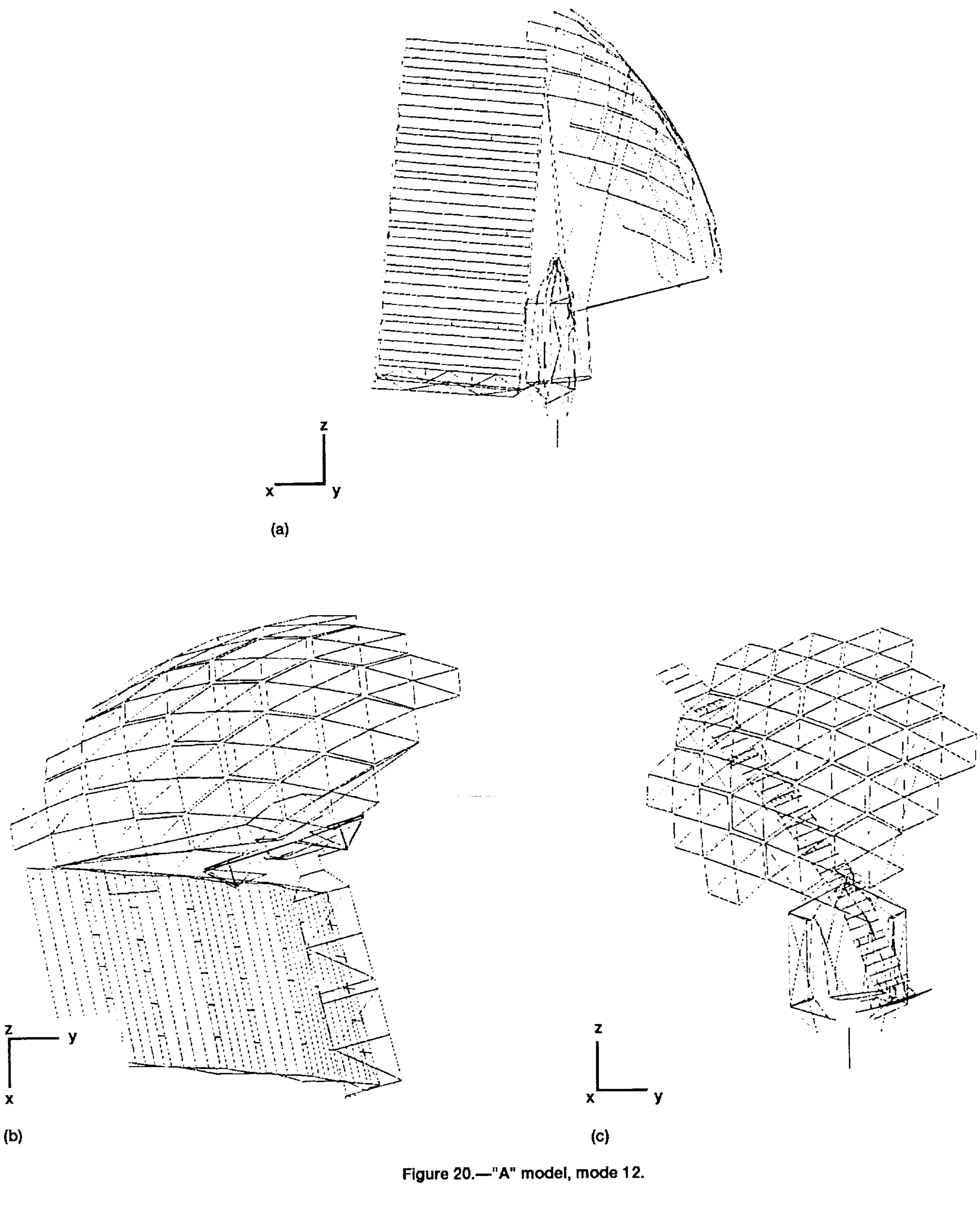


Figure 20.—"A" model, mode 12.

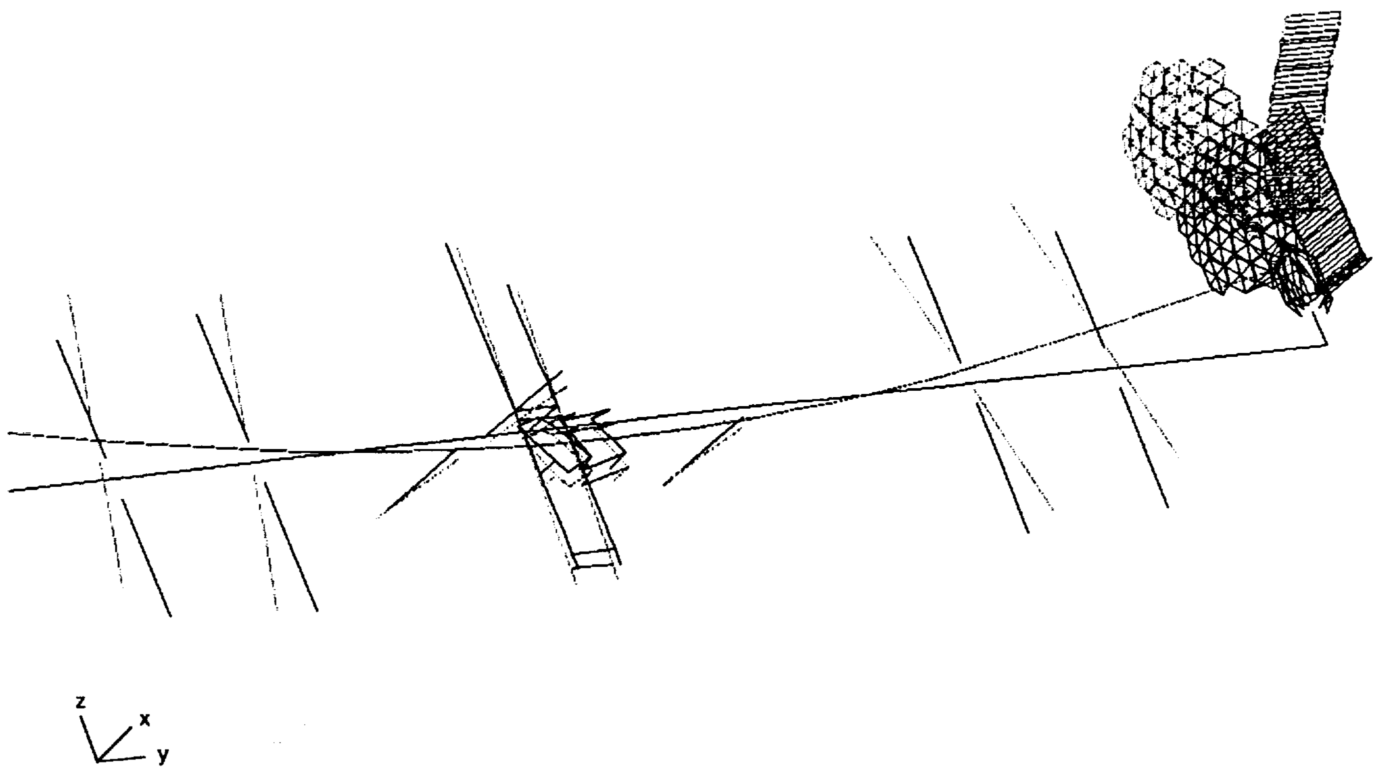
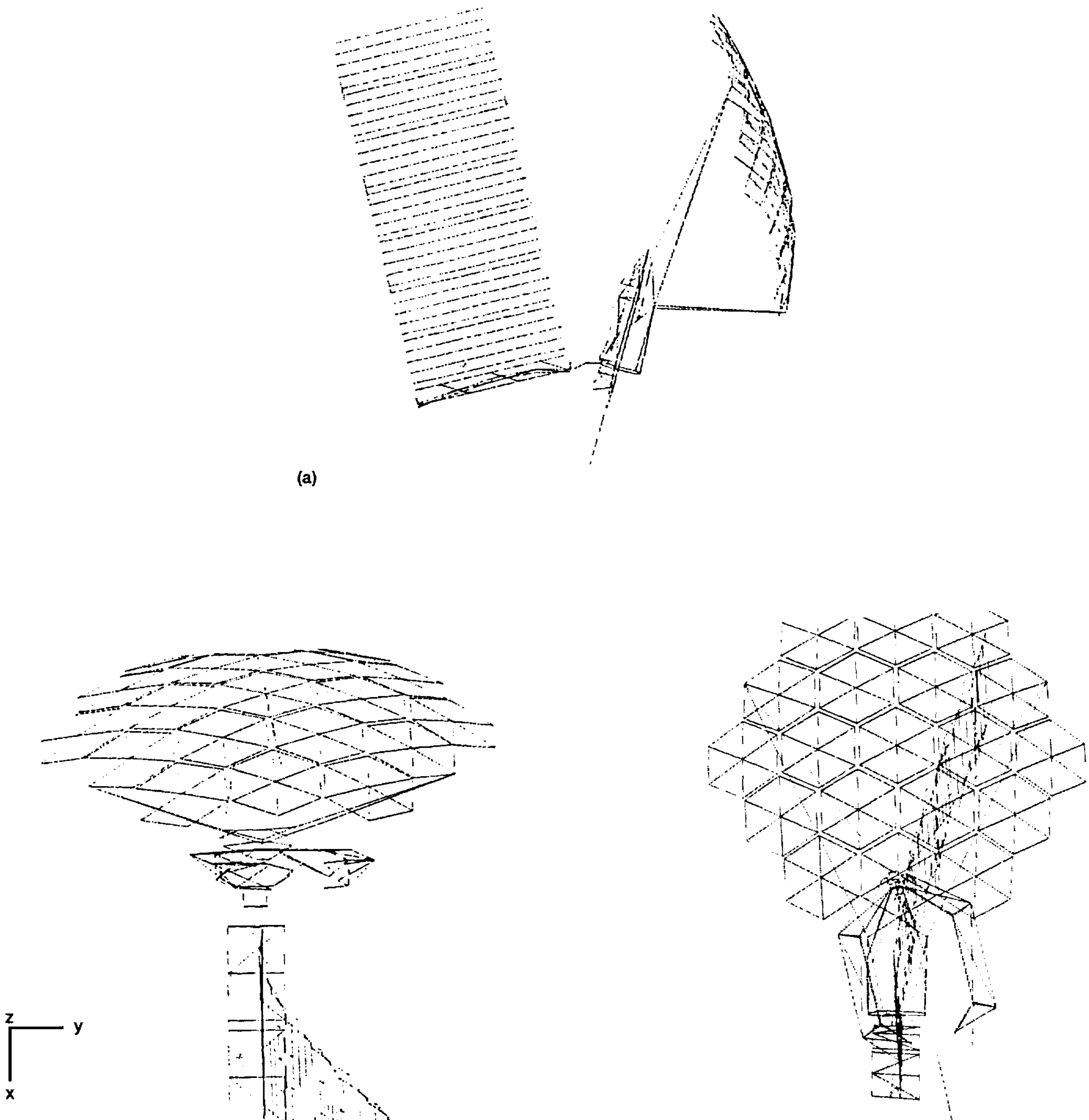


Figure 21.—"A" model, mode 13.



(a) (b) (c)

Figure 22.—"A" model, mode 13.

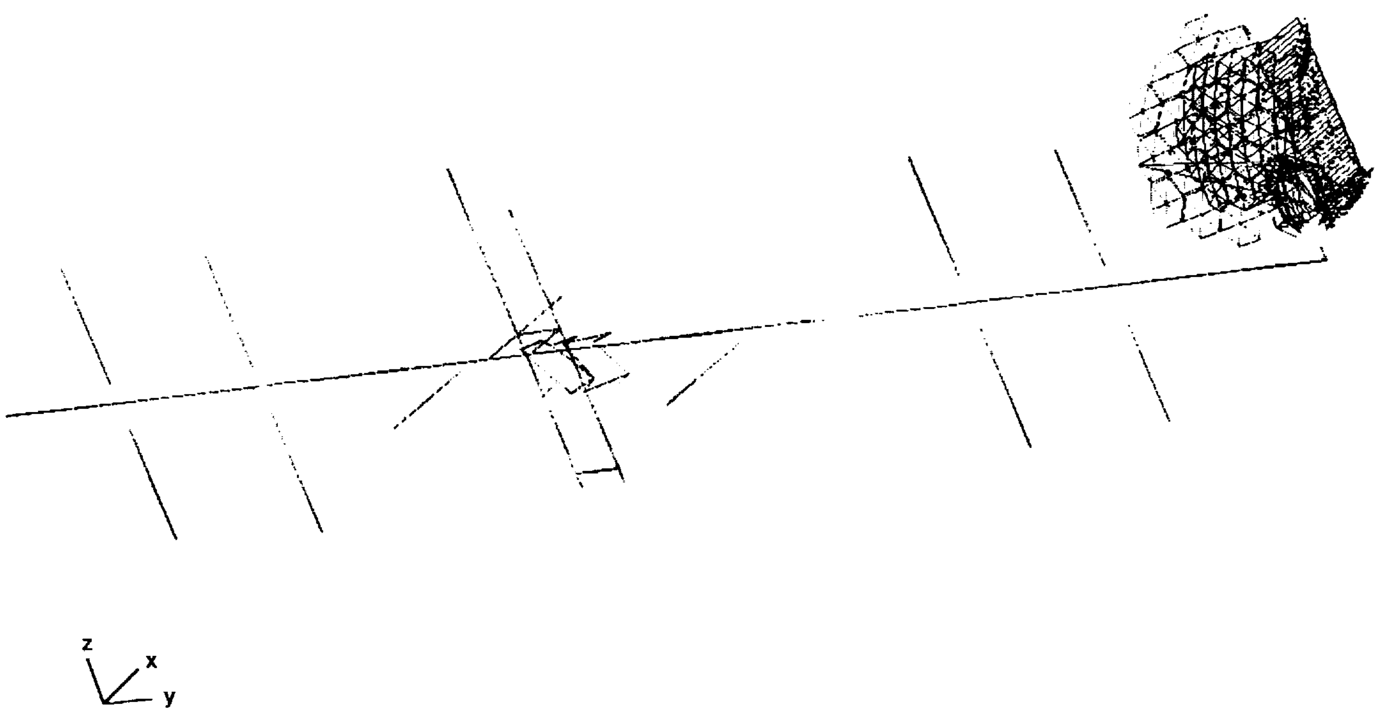


Figure 23.—"A" model, mode 14.

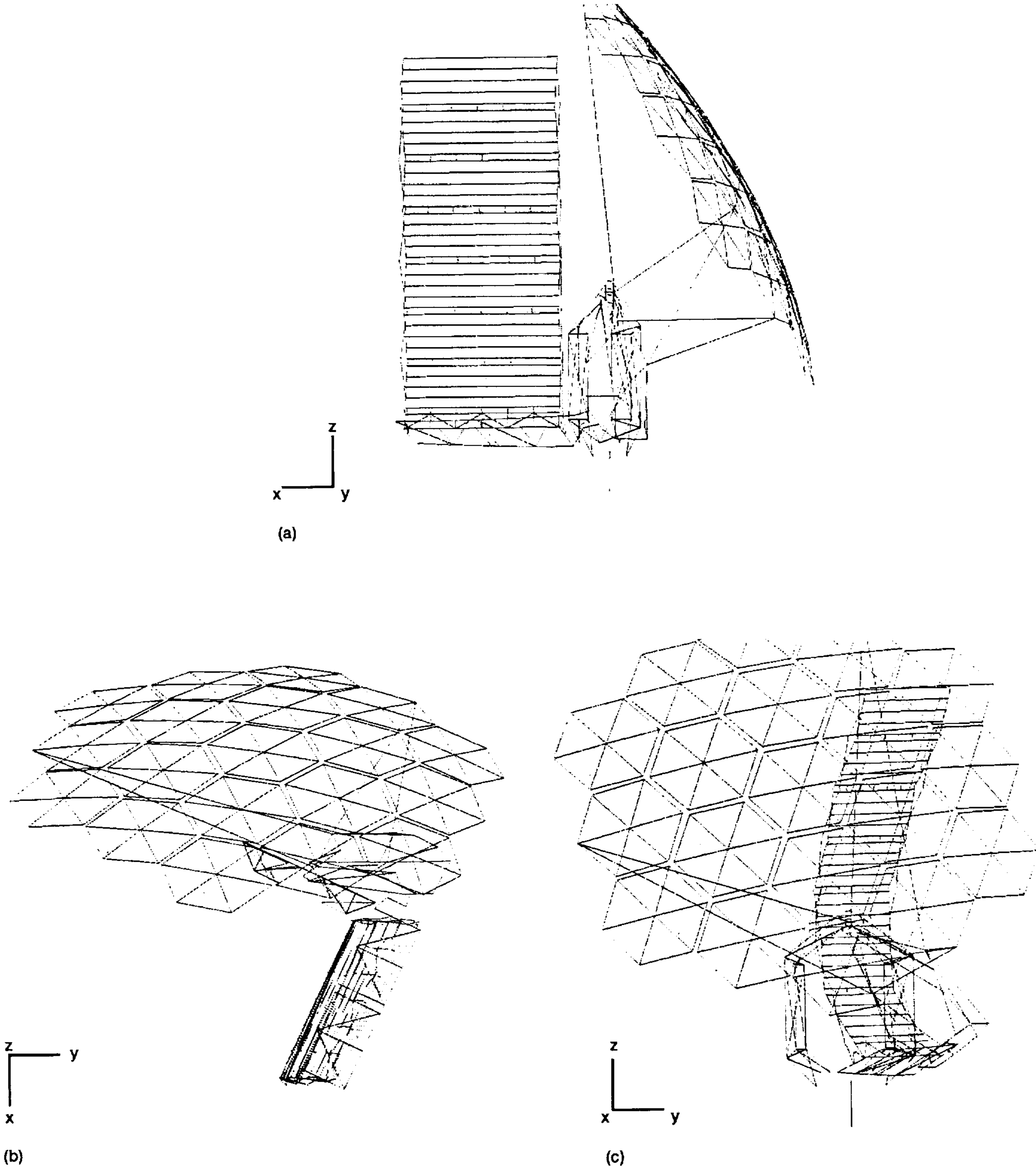


Figure 24.—"A" model, mode 14.

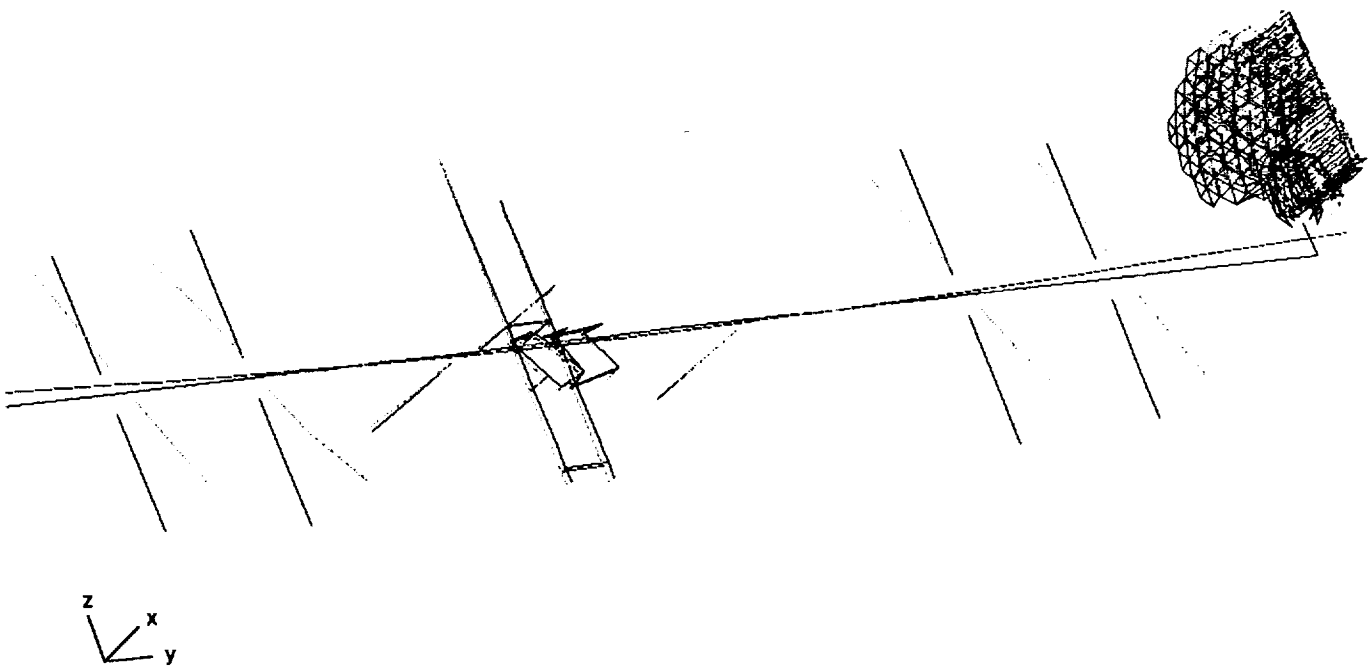


Figure 25.—"A" model, mode 15.

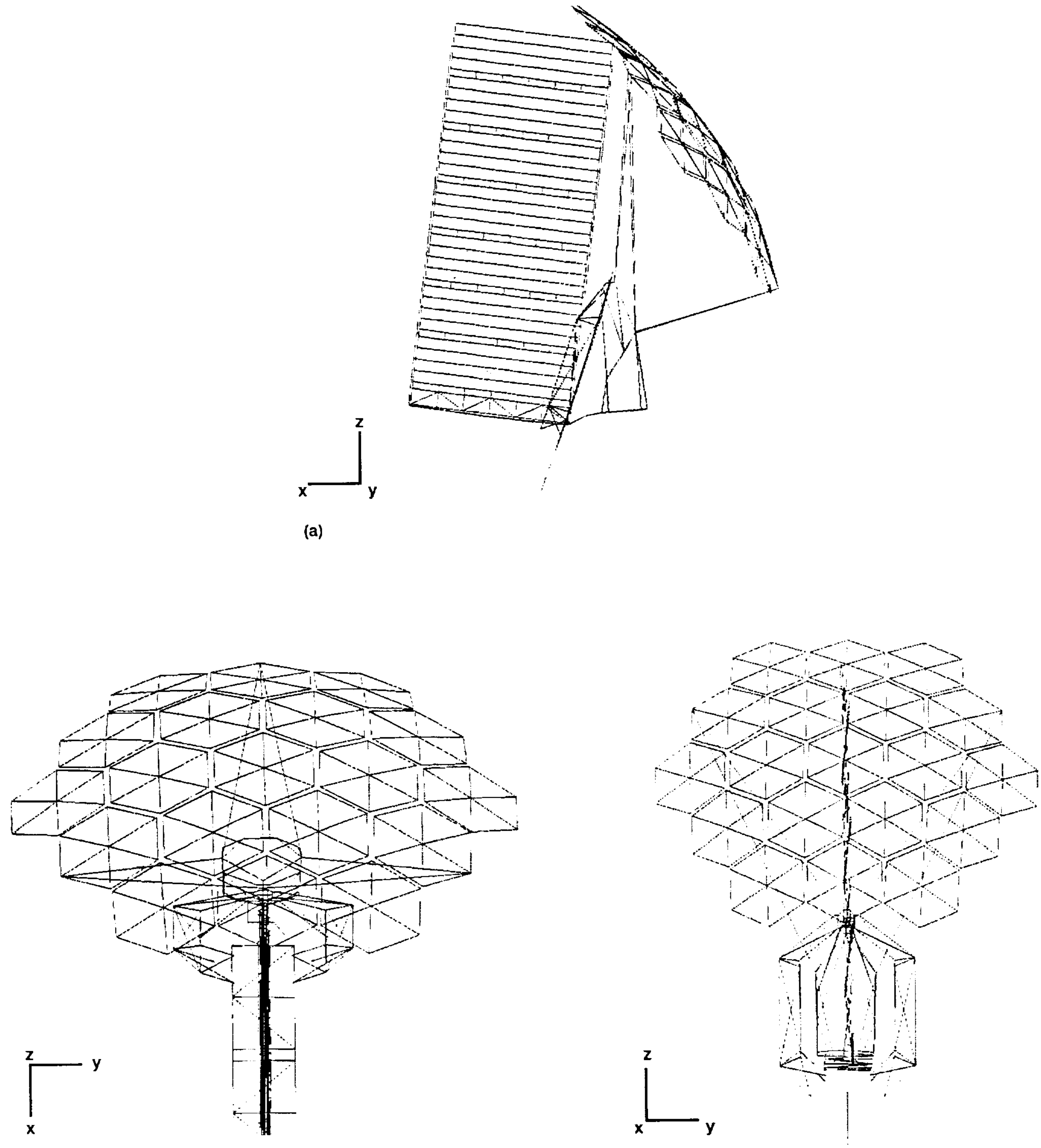


Figure 26.—"A" model, mode 15.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-104506		

4. Title and Subtitle
Space Station Freedom Solar Dynamic Modules Structural Modelling and Analysis

5. Report Date
December 1991

6. Performing Organization Code

7. Author(s)
Charles Lawrence and Ron Morris

8. Performing Organization Report No.
E-6367

10. Work Unit No.
505-63-1B

9. Performing Organization Name and Address
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

11. Contract or Grant No.

13. Type of Report and Period Covered
Technical Memorandum

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

14. Sponsoring Agency Code

15. Supplementary Notes
Charles Lawrence, NASA Lewis Research Center; Ron Morris, Sverdrup Technology, Inc., Lewis Research Center Group, 2001 Aerospace Parkway, Brook Park, Ohio 44142. Responsible person, Charles Lawrence, (216) 433-6048.

16. Abstract
In support of the Space Station Freedom Solar Dynamic Power Module effort, structural design studies were performed to investigate issues related to the design of the power module, its pointing capabilities, and the integration of the module into the Space Station Freedom infrastructure (fig. 1). Of particular concern from a structural viewpoint are the dynamics of the power module, the impact of the power module on the Space Station dynamics and controls, and the required control effort for obtaining the specified Solar Dynamic Power Module pointing accuracy. Structural analyses were performed to determine the structural dynamics attributes of both the existing and the proposed SD module designs. The objectives of these analyses were to: 1. Generate validated Solar Dynamic Power Module NASTRAN finite element models. 2. Combine Space Station and power module models into integrated system models. 3. Perform finite element modal analyses to assess the effect of the relocations of the power module C.M. (Center of Mass), and provide modal data to controls designers for controls system design.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Space stations Dynamic structural analysis Finite element method	Unclassified - Unlimited Subject Category 39

19. Security Classif. (of the report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified	24	A03

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161